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THE ROLE OF BUILDINGS ENERGY EFFICIENCY IN REDUCING AND CONTROLLING PEAK ELECTRICITY DEMAND

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I. WHY DO WE CARE ABOUT PEAK DEMAND?

Electricity demand varies hourly. At times of low demand, only the utility's most efficient plants need operate, while at peak times, almost all of the utility's available power plants must run to meet the demand and prevent system outages. The electric utility industry has traditionally focused on peak demand because the likelihood of system outages (measured by the so-called "loss of load probability" or LOLP) is by far the greatest at peak times (Kahn 1988). LOLP is typically concentrated in a relatively small number of hours per year, and those hours are usually near to the time of system peak.

The reasons why peak times are so likely to be associated with system outages are several-fold:

- Real time delivery: Electricity cannot be stored, and thus must be supplied at the same time that it is being used.
- Long lead times: Generation capacity is fixed in the short term, and adding new capacity can take anywhere from one year to ten years.
- Lack of responsiveness to real-time costs: Demand is typically not responsive to the cost of supplying power in real time (costs per kWh at time of system peak can be several times the retail rates charged to customers). These retail rates might vary seasonally, but only rarely are responsive to daily changes in prices, in part due to the widespread lack of metering technology capable of charging customers for their electricity use in real time, and an associated lack of end-use device technology capable of responding to such price signals in real time.

For these reasons, the time of system peak demand has been a preoccupation of utility planners for many years. In addition, utilities are concerned with peak demand because they don't recover all of their costs at peak times, which is not a reliability concern, but a financial one. Finally, utilities are concerned not just with the system peak demand, but with local and regional peak demands that may result in outages due to local transmission, distribution, and generation constraints.

Society is rightly concerned about peak demand for other reasons as well:

- Economic efficiency: The utility must have large amounts of generating capacity available for peak times, but this capacity sits idle for most of the year. If electric load curves could be flattened (through efficiency improvements or price responsiveness) then a more efficient use of society's capital could result. In addition, when the utility system is close to peak, small reductions in demand can lead to large reductions in marginal costs per kWh, because of the inelasticity of supply at that time.

- Environmental quality: The utility's most inefficient and polluting plants must run at peak times, (because almost all plants must run to meet the system peak).

- Fuel security: Many peaking and intermediate load plants are fired by natural gas or (to a lesser extent) fuel oil, raising issues of fuel security and diversity.

A broader way to characterize the problem is that of correcting supply-demand imbalances. As shown by the California power crisis in 2000 and 2001, power outages can occur during even low demand times if insufficient generating capacity is available at those times (REF). Reducing demand at times when the system is in danger of outages can be an effective way to improve system reliability. The discussion in this paper is applicable to any times when demand threatens to outpace available capacity, whether or not those times occur at time of system peak.

To avoid confusion and allow accurate comparisons, it is important to first define key terms. We use the term *electricity use* to refer generally to electricity consumption measured over any time period. This includes both *annual consumption* (energy) and *instantaneous load* (power). *Peak load* is the maximum simultaneous electricity demand for some portion of the electrical system, typically averaged over an hour. *End-use peak load* is measured at the customer's electricity-using equipment. *System peak load* is measured at the power plant busbar, representing the load served by generating plants[1]. The simultaneous peak load for all end-users (e.g., statewide) is referred to as the *coincident peak load*. Subgroups of end-users (e.g., a utility service territory, or all industrial customers) will have their own simultaneous peak load, which is referred to as *non-coincident peak load* for a sector or customer class. Many analysts use the terms *demand* and *load* interchangeably.

II. DRIVERS OF PEAK DEMAND

Many factors influence peak demand, including weather and government policies, as well as trends in demographics, economic activity, market shares, technology, and end-user behavior. We treat each of these factors in turn.

- Weather: Peak demand is often strongly correlated with weather. For utilities in warmer regions of the U.S., peak demand is in the summer, and is driven mainly by air conditioning loads on the hottest summer afternoons. For colder regions, peak demand is in the winter, and is driven by the demand for electric heating on

[1] System loads are reported by utilities to the Federal Energy Regulatory Commission (FERC).

the coldest nights of the year. Some utilities in the middle latitudes of the U.S. have summer and winter peaks of comparable size.

- Government & utility policies: Any implementation policies that affect the efficiency of buildings and equipment can also influence peak demand. Equipment efficiency standards, building codes, voluntary programs (like the EPA/DOE ENERGY STAR program), government procurement, and utility rebate programs all can have an effect in the short to medium term. Government Research and Development (R&D) can have a longer-term effect on peak demand, by making higher efficiency options available that would not have existed in the absence of the R&D (or by accelerating the availability of such technologies).

- Demographics: Demographic trends affect settlement and equipment use patterns. For example, much of the recent growth in the U.S. housing stock has occurred in the Southern and Western parts of the U.S., where air conditioning loads are large. Trends in household size, lifestyle, and age of household occupants also influence daily equipment usage.

- Economic activity: Economic trends are tied partly to demographics, but also to business cycles and regional developments. Strong economic growth in a particular region will lead to more building construction and migration to that area, thereby increasing total electricity use and peak demand.

- Market shares: Equipment ownership trends can affect peak demand, if newly popular equipment uses electricity more at time of peak demand than the average appliance. For example, large purchases of room air conditioners during a heat wave can have a measurable effect on a utility's summer peak demand. Another example would be the trend towards larger commercial buildings that are dominated by internal loads and that require cooling all year round in many climates.

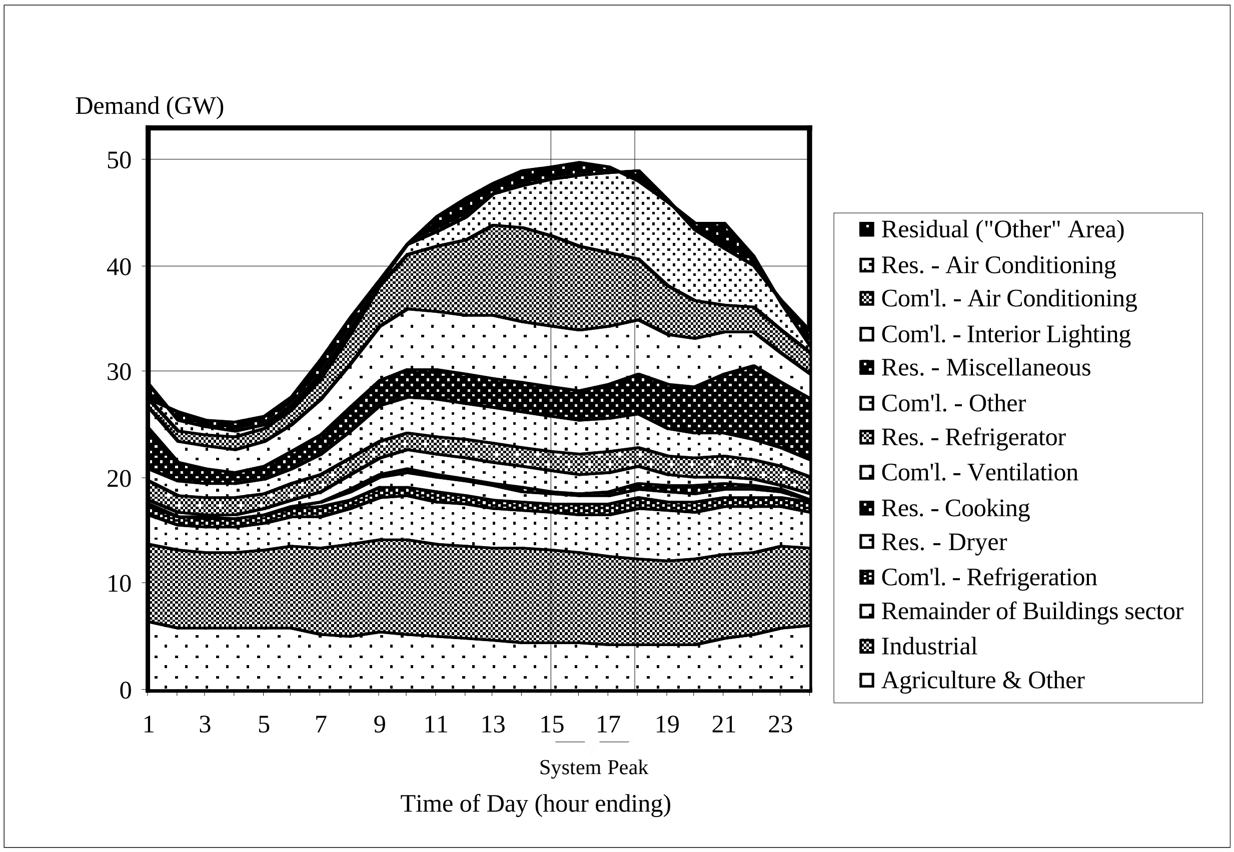
- Technology: Adoption of new technology in existing end-uses can affect peak demand. The rising popularity of the flat-panel Liquid Crystal Display (LCD) screens is one example of this phenomenon, where this new technology uses one-third to one-half as much power as the Cathode Ray Tube that it replaces.

- End-user behavior: How people use their appliances matters. The California electricity crisis in Summer 2001 was ameliorated in part because of changes in end-user behavior brought about by advertising by the state and the utilities, as well as by heightened awareness of the crisis from all the news media attention.

These trends culminate in peak demand curves that often look like Figure 1, taken from Brown and Koomey (2002). This curve is for the summer peak day in California in 1999, and it shows a ratio of about two for the highest to the lowest load on that day. The graph demonstrates the importance of residential and commercial air conditioning and commercial lighting to the maximum demand on that day (those three end-uses account for about 40% of total peak load during the peak hours).

Total summer peak demand in the U.S. is about 700 GW in 2001, as reported by the North-American Electric Reliability Council (NERC 2001). This reported load is the sum of the coincident peak demands for the various regions making up NERC, but it is not the coincident peak demand that would result if the U.S. was a completely integrated single utility system. Typical winter peak demands for the U.S. are something over 600 GW.

Figure 1: California 1999 Summer Peak-day End-use Load (GW): 10 largest coincident building-sector end-uses and non-building sectors



Source: LBNL analysis of CEC and FERC data (Brown and Koomey 2002).

[a] Residual is the difference between FERC system loads and CEC forecasting model outputs (mainly due to small utilities not covered by the CEC forecasting model).

[b] Agriculture sector includes water pumping.

[c] Other sector includes transportation and street lighting.

III. KEY PEAK DEMAND ISSUES

TECHNOLOGIES

Table 1 shows the four major categories of technologies that can affect utility peak demand: Load reducing, load shifting, high efficiency, and on-site generation.

- Load reducing technologies are those that reduce service demands, such as load controls for buildings and equipment, and behavioral changes such as turning off lights. They are distinct from load shifting and efficiency technologies.

- Load shifting technologies are those that involve shifting loads to off peak periods, using energy storage or smart controls. Thermal (cooling) storage systems are often used by customers who have high demand charges, or time-of-use or real-time rate schedules. These systems make ice during off-peak times and use that ice to cool the building during peak times, thus shifting the electricity load. During the electricity crisis in California, the California Energy Commission (CEC) advocated an even simpler form of thermal storage, where building owners would cool their buildings down in the morning, and allow them to "coast" through the afternoon at a higher thermostat setpoint, thus effectively shifting the load to the off peak times.

- High efficiency equipment reduces the energy needed to deliver a given level of energy services, or (equivalently) produces more energy services per unit of energy and demand input. For example, high efficiency electronic ballasts can reduce electricity use and peak demand by about one-quarter compared to conventional magnetically ballasted lighting technologies if combined with more efficient lamps.

Table 1: Categories of technologies that can affect peak demand

Load reducing	Load shifting
Load control glazings Daylighting Lighting and AC controls Better building design Cool roofs Shading Efficient humidity control Behavioral changes (turning off the lights) Energy management systems Building commissioning	Real time control of power use (grid interactive price response) Energy management systems Thermal storage (e.g. CEC's precooling of building prior to peak) Waste heat recovery
High efficiency equipment	**On-site energy generation**
Cooling (including natural gas cooling technology?) Lighting Water heating Refrigeration Others Building commissioning	Building integrated photovoltaics Fuel cells Microturbines Cogeneration Microgrids

- On-site energy generation reduces the demands seen by the utility grid, although it does require additional energy input (usually natural gas or biomass, although other renewables such as wind and photovoltaics are becoming increasingly common).

Each of these technological approaches can contribute to efforts to affect peak demand.

POLICIES

We break up the policies that can affect peak demand into four categories of actions: mandatory, voluntary, incentives/pricing, and R&D.

- Mandatory actions include appliance & equipment standards, building codes, and state implementation plans (SIPS). SIPS are mandated under the Clean Air Act, but achieving those mandated pollution reductions can be achieved by states and localities using various types of programs, including any of the others discussed below.

- Voluntary actions include the ENERGY STAR labeling program, technology procurement initiatives by government and business, and exhortations to turn off the lights and turn down the thermostat. Such voluntary programs have proven especially effective when applied

- Incentives/pricing strategies include utility rebates/resource acquisition, modifying utility regulatory structure/incentives, and pricing/metering strategies (including time-of-day, real-time, and weather-linked prices). Utility rebates are given directly to customers and manufacturers of energy using equipment to promote more efficient products, while incentives can also be given to utilities to encourage them to promote efficiency by their customers. Pricing strategies will grow in importance over time as metering technology drops in price and grows in sophistication.

- R&D is a critically important policy for the medium to longer term. Peak demand has only occasionally influenced R&D directions, but a focus on R&D can lead to innovations that will substantially affect peak demand.

Each of these policies have been successfully used at various times and places, and each has a role to play in any successful efforts to develop, deploy, and promote new technologies to reduce peak demand.

SEASONAL ASPECTS OF ELECTRIC PEAK DEMAND

Peak demand issues vary by season. In summer peaking utilities, cooling and lighting loads dominate, as shown in Figure 1 (above). Most U.S. utilities are summer peaking, and the focus therefore is usually on those end-uses. In winter peaking utilities, electric resistance heating tends to drive peak demands, although lighting and other end uses typically also play a role. Heat pumps often have electric resistance backup, so a very cold period can result in substantial use of that backup source, thus exacerbating winter peak issues.

ARE THERE PEAK DEMAND ISSUES FOR NATURAL GAS?

There also may be issues affecting the supply of natural gas or oil, either to end-users or to utilities. For example, a shortage of natural gas to a particular region could result in more residences using backup electric resistance heating that winter, thus increasing electricity demand and worsening the supply/demand imbalance. That same shortage could also affect the supply of natural gas fired electricity generation from the utility or from its industrial customers, also exacerbating the electricity supply/demand imbalance. These fuel shortages can be seasonal, or could be related to transmission and distribution constraints brought about either by physical limitations or by manipulation of the few large firms who typically control pipelines into a given region. They can also be related to larger global energy developments, such as an oil price shock, or to unexpected new uses of natural gas that arise from newly sited cogeneration facilities or new energy service demands (e.g. gas barbeques, outdoor gas lighting, fireplaces). Such new demands can be related to clean air regulations in some places, so this is yet another point where policies can affect the peak electricity demand issue.

WHAT ARE THE KEY BEHAVIORAL AND SOCIAL SCIENCE RESEARCH QUESTIONS?

The most important behavioral questions fall into three areas: the response of consumers and businesses to direct incentives and voluntary efficiency programs promoting purchase of more efficient equipment, the response of consumers/businesses to exhortations to conserve either during a power crisis or during "normal" times, and the response of those same customers to time-of-use or real-time pricing signals. We treat each of these in turn:

- Purchase of more efficient equipment: Much of the program evaluation work for demand-side programs run by electric utilities has focused on the issue of the response of customers to incentives to purchase more efficient equipment (Eto et al. 1994, Eto et al. 1995). There are still many questions to be answered about the best ways to design rebate programs to achieve high adoption rates, low free ridership, and low implementation costs.

- Exhortations to conserve: One of the unexpected events of the California electricity crisis was the strong behavioral response exhibited by consumers in the face of strong exhortations from the California state government to conserve. This strategy had not been tried since the late 1970s, and in contrast to the mixed success of the U.S. government's requests at that time to drive less and turn down the thermostat, the California campaign was a major reason why there were few if any blackouts in the summer of 2001. One of the key social science questions relates to the conditions under which such exhortations will be successful. Another involves the question of persistence: how many of the behaviors induced by exhortation will remain in place after the crisis has passed?

- Time-varying price signals: The response of electricity customers to price signals is the biggest wildcard of all, and the one with the most potential to transform radically the way the electricity system operates. Demand is now essentially inelastic in the short run—the prices customers are charged do not reflect the time-varying cost of generating electricity at peak times. Before time-varying price signals will achieve widespread short-run influence a large number of facilities will need to install appropriate meters and purchase appliances and equipment that can respond automatically to changing prices. California is conducting a pilot program of this type, but the state is still years away from widespread adoption of such technology. The question of what kind of response such technology will evoke still looms large in any assessment of how peak demand issues will be treated in the future.

Because peak demand is directly linked to human behavior, the social science dimension must be addressed in any successful assessment of peak demand issues.

WHAT ARE THE GEOGRAPHIC COMPONENTS OF THE ISSUE?

Geography plays a key role in peak demand. Geography is important because of its relationship to weather and climate, but also because settlement patterns and siting constraints for generation and transmission lines have a geographic component as well.

- Weather and climate: Weather and climate affect the shape of load curves. Air conditioning load curves are spread more evenly over each day in Mississippi or Texas, which are hot and humid throughout the summer, than in California, where summers are dry and nights are often cool.

- Settlement patterns: Much of the housing growth in the U.S. over the past few decades has occurred in the southern and western U.S., where air conditioning is ubiquitous and the electricity consumption associated with air conditioning is large on a per household basis. Such trends in settlement patterns have obvious implications for peak demand growth.

- Transmission, distribution, and generation siting constraints: The U.S. electricity grid is not a national one. Most regions of the North American Electric Reliability Council have transmission capacity constraints to other regions. In addition, local constraints on distribution and generation facilities, mainly caused by siting constraints, can contribute to local outages in extreme circumstances.

Some of these geographic issues are amenable to treatment using geographic information systems, also known as GIS (May et al. 1996). Such computer tools are becoming more widely used as analysis and evaluation of program impacts shifts from calculations based on national averages to those based on statistically representative samples of households and commercial buildings (see, for example, (US DOE 2000)). Utilities have made wide use of GIS for analyzing siting issues related to construction of transmission, distribution, and generation facilities, and these same tools can be applied to ameliorating peak demand problems, but have not thus far been used for that purpose.

WHAT IS THE STATE OF DATA ON PEAK DEMAND IN BUILDINGS?

Little work has been done on peak demand issues in the past decade, in large part because electric capacity had been more than adequate to meet demand in almost all regions during this period. The events of 2000 and 2001 in California have again focused attention on peak demand, and in particular the potential contribution of technologies and policies to affecting peak demand to minimize economic disruptions when supply and demand are out of balance. To realize this potential will require renewed attention to data collection in this area.

Many utilities collect load data by customer class for use in rate-setting proceedings (Sorooshian-Tafti 1989), but it has been many years since measurements of end-use load shapes were widespread. The data collected have covered individual end-uses such as lighting, cooling, and water heating (Ontario Hydro 1984). A few studies have been more comprehensive for the residential (Brodsky and McNicoll 1987, Eto and Moezzi 1993, Ruderman et al. 1989) and commercial (ADM Associates 1989, Kasmar 1992, Pratt et al. 1990) sectors. Some of these data have made their way into computer models of hourly loads (McMahon et al. 1987, Ruderman and Levine 1984). Very few studies have measured end-use load *savings*, which is a much more difficult task, but it is essential for characterizing the peak demand impacts of efficiency options and for comparing those options to power plants.

The data needed include both baseline measurements and measured savings from efficiency options. Hourly load shape data are the most useful, but are also the most expensive to collect and most difficult to use. To create statistically representative load shapes for buildings at the end-use level requires hourly sub-metering of individual appliances in hundreds of buildings. Such efforts are of course expensive and time consuming, and other approaches (like conditional demand analysis) have been used to supplement such metered data. There's still no real substitute for metering, however.

Load shape data can be aggregated in various ways to make their collection and use more straightforward. The conservation load factor (CLF) is a one-parameter summary of load shape characteristics that relates the average demand savings to the peak load savings from an efficiency measure. The CLF is useful because it allows straightforward comparisons between supply and demand technologies (it is analogous to the capacity factor for a power plant) and because it is a compact way to summarize load shape characteristics for efficiency options. The original work on this approach created CLFs for both technologies (Koomey et al. 1990b) and efficiency programs (Koomey et al. 1990a), but the scope of that work was limited by available data.

IV. IS THERE A UNIQUE FEDERAL ROLE IN ADDRESSING THESE ISSUES?

Many different institutions and individuals have an interest in peak demand issues, including electric utilities, appliance manufacturers, building developers, DOE (including the Federal Energy Management Program, FEMP), EPA, National Institute of Standards and Technology (NIST), consumers, electricity-service providers, and various non-governmental organizations. Because of their keen financial interest in minimizing peak demand, utilities have traditionally led the charge on treating this issue, but there are some areas that only the Federal government can address. In particular, changes in government programs like minimum efficiency standards, test procedures, and ENERGY STAR voluntary programs must be undertaken at the federal level. Funding long-term R&D is also generally acknowledged to be an appropriate role for the Federal government. Finally, data collection, compilation, and analysis activities are most cost-effectively conducted at the Federal level, since there are large economies of scale in such efforts, and individual states or utilities have little incentive to compile and make available information from other regions.

V. WHICH POTENTIAL SOLUTIONS TO THE PEAK DEMAND ISSUES IN III FALL UNDER THE PURVIEW OF BTS?

We list here broad categories of potential solutions, including mandatory actions, voluntary actions, incentives/pricing strategies, R&D, and data collection & analysis, and we focus the discussion on solutions that BTS is particularly well suited to implement.

- Mandatory actions: BTS could promote the modification of future efficiency standards for key end-uses to better reflect peak demand concerns.[2] For example, Central Air Conditioner (CAC) efficiencies could be specified not just as a seasonal energy efficiency ratio (SEER) but as an energy efficiency ratio, which would more accurately measure the impact of an efficient CAC on peak demand.

- Voluntary actions: For the DOE ENERGY STAR products (and related procurement programs), the specifications for qualifying products are periodically made more stringent, and the next phase of such revisions could explicitly specify criteria that would help reduce peak demand. DOE can assist states and utilities to develop successful exhortations to conserve by making information widely available on energy and peak demand impacts from efficient technologies.

- Incentives/pricing strategies (including giving utility rebates for peak reductions/load shifting and changing utility regulation to give incentives to utilities for implementing efficiency) are largely under the control of utilities and state regulators. BTS may have a role in collecting data on the effectiveness of such efforts because they affect the adoption of technologies in buildings.

- R&D is a critically important policy for the medium to longer term. Peak demand has only occasionally influenced R&D directions. It is especially important to identify new R&D areas that are not currently part of EERE's portfolio but that show promise for reducing peak demand for certain end uses. For example, BTS may have a role in developing the metering and new equipment control technologies that will allow time-varying price regimes for electricity to finally achieve their full potential—far too little recent work has been done in this area,

[2] If test procedures were to be updated to treat peak demand, there are presumably other corrections and additions that could be made (e.g. measurement of standby power) that would be relatively easy to add and would improve the test procedures immensely.

and the potential long-term payoff is huge. It will require coordination with other parts of DOE who focus mainly on the utility side of the meter.

- Data collection and analysis for energy efficiency technologies has traditionally been an important area for BTS, and the peak demand issue is no exception. As discussed above, little measured data has been collected at the end-use level since the early 1990s, and that lack has been sorely felt. The introduction of real-time or time-of-use pricing and control has great potential, not just for ameliorating the peak demand problem but also for making available large amounts of time-varying end-use load data.

BTS is in a unique position to solve some of the key issues surrounding peak demand, by affecting policy design, funding research, and collecting data.

VIII. Conclusions

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